Binary Exoplanet Host Star Orbital Period Distribution

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SUMMARY

We present high-resolution speckle interferometric imaging observations of TESS exoplanet host stars using the NN-EXPLORE NESSI instrument at the 3.5-m WIYN telescope. Speckle observations of 186 TESS stars were carried out and 45 (24%) likely bound companions were detected. This is approximately the number of companions we would expect to observe given the established 40-50% binarity rate in exoplanet host stars.

For the detected binaries, the distribution of stellar mass ratio is consistent with that of the standard Raghavan distribution and may show a decrease in high-q systems as the binary separation increases. The distribution of binary orbital periods, however, is not consistent with the standard Ragahavan model and our observations support the premise that exoplanet-hosting stars with binary companions have, in general, wider orbital separations than field binaries. We find that exoplanet-hosting binary star systems show a distribution peaking near 100 au, higher than the 40-50 au peak that is observed for field binaries. This fact led to earlier suggestions that planet formation is suppressed in close binaries.

THE SAMPLE

During the time period 6/2019 to the present, we observe TESS target stars from the mission's list of TESS Objects of Interest (TOIs). The majority of the targets were from the TESS year 2 northern sky survey, with a few equatorial year 1 southern sky targets added in. All of the observations reported here were made with the 3.5-m WIYN telescope located on Kitt Peak in Southern Arizona and the observing time was allocated through the NN-EXPLORE program via peer review. The figure below shows the stellar sample as a function of the Gaia (G) magnitude in both distance and effective temperature.

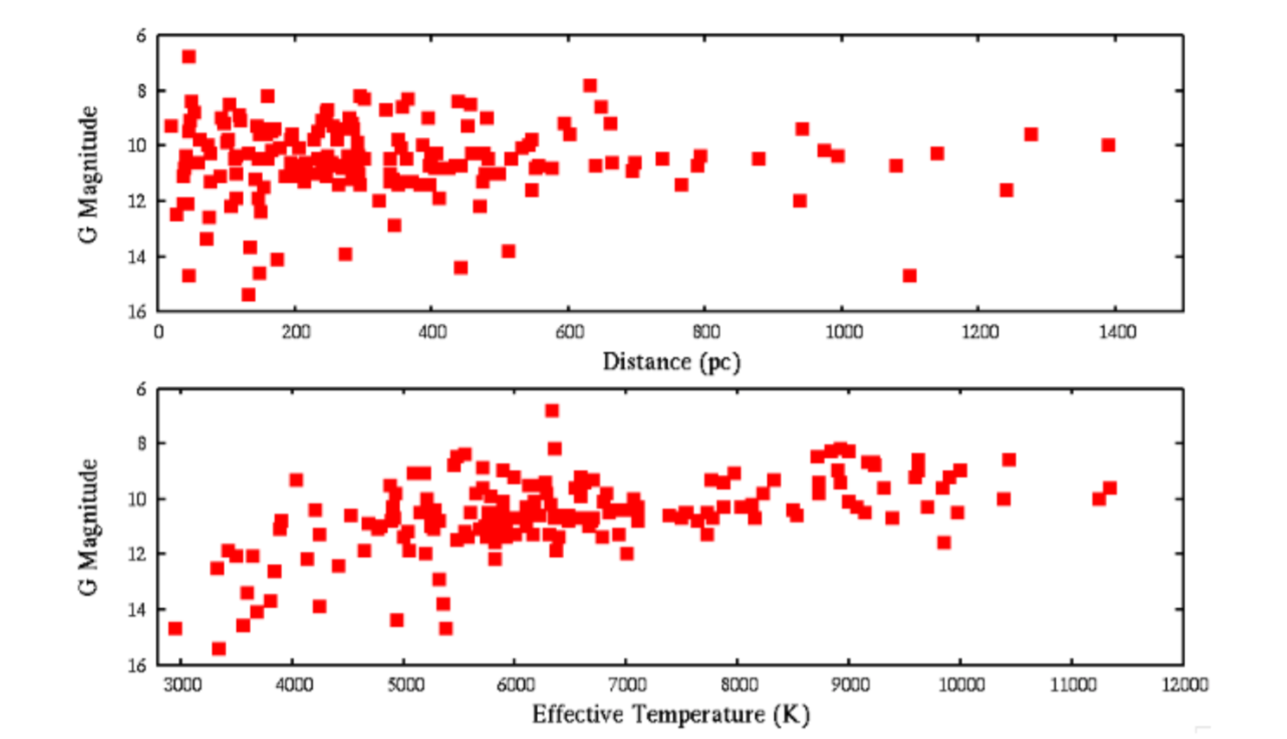
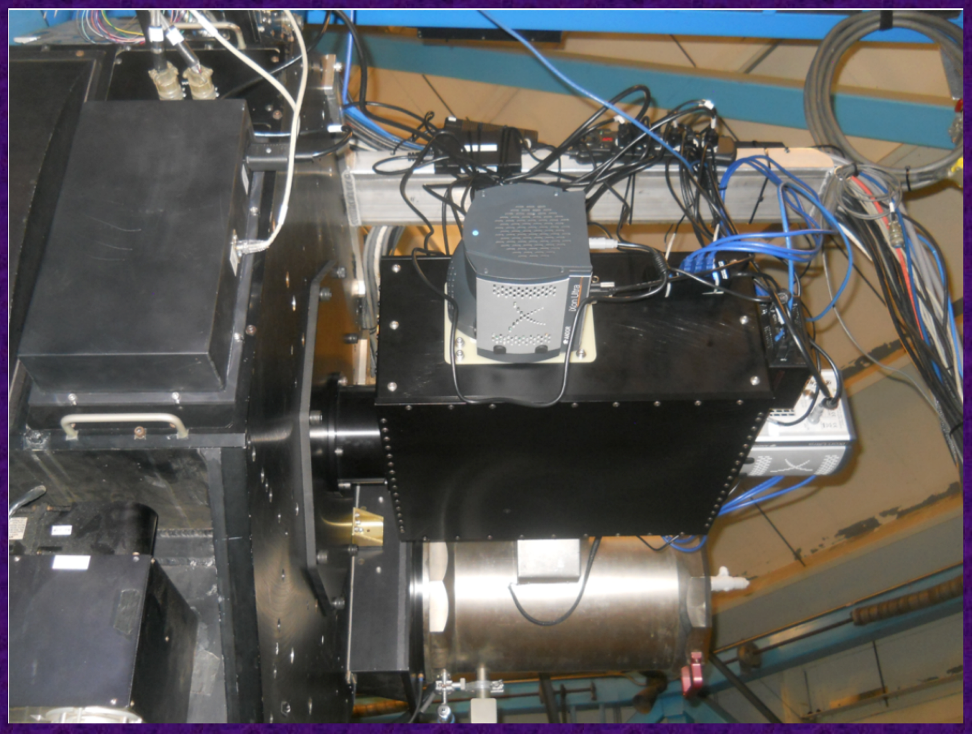


Figure 1: Properties of the TESS stars in our sample. Referenced to the Gaia apparent magnitude, these plots show the distribution of the distance and effective temperature within the sample. Most stars are near 10-11th magnitude, closer than 500 pc, and cooler than 7000K. A few more distant and hotter stars are not shown (See Table 1).

THE OBSERVATIONS

The majority of the observations were made with the NESSI instrument while a few older observations (of TESS/Kepler targets) were made with the DSSI instrument. Both instruments are designed to obtain speckle interferometric observations, that is rapid exposures (40 msec) that are then combined using Fourier techniques and producing a high-resolution reconstructed image of the scene. We used these analysis steps to search each target for companion stars, especially those very close in angular distance, likely to be true, bound companions.



NESSI mounted on the WIYN 3.5-m telescope (black box with its two EMCCD imaging cameras sticking out). The silver cylinder behind and below is the WIYN Near-IR imager, WHIRC.

Read all about it !!! – Howell, S. B., et al. 2020, submitted

HIGH-RESOLUTION CONTRAST CURVES AND DETECTED COMPANIONS

The figure below presents the limiting 5-sigma 832 nm contrast curve for the NESSI instrument when used on the WIYN Telescope. Shown for comparison is the SOAR Hi-resolution camera I-band curve. The filled blue squares show the locations of the companions we detected at WIYN.

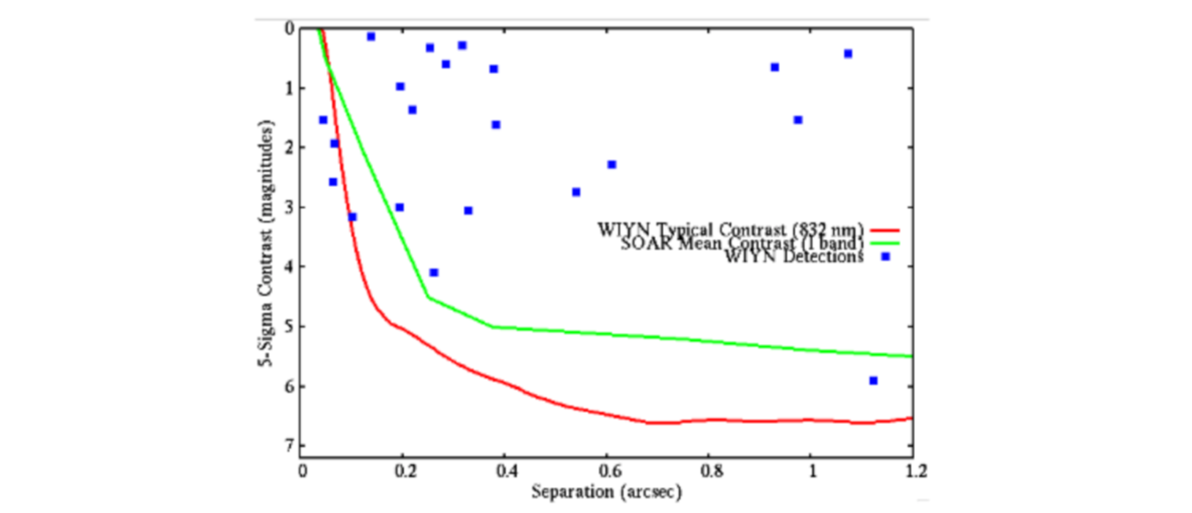


Figure 4: Speckle imaging 5-Sigma mean contrast curves. The SOAR I-band curve is from Ziegler et al. (2020) and the WIYN 832 nm curve is from Scott et al. 2018. The two contrast curves essentially match near the diffraction limit of the telescopes (SOAR is 4.1-m and WIYN is 3.5-m), with the WIYN 832 nm contrast limit being deeper at all separations. The stellar companions detected at WIYN inside 1.2 arcsec are shown including four inside 0.1 arcsec that would not be detected at SOAR.

For each detected companion, we show below the range of possible companions with limits showing those accessible to our observations. In each figure, we mark the location of the actual detected companion for these sample stars.

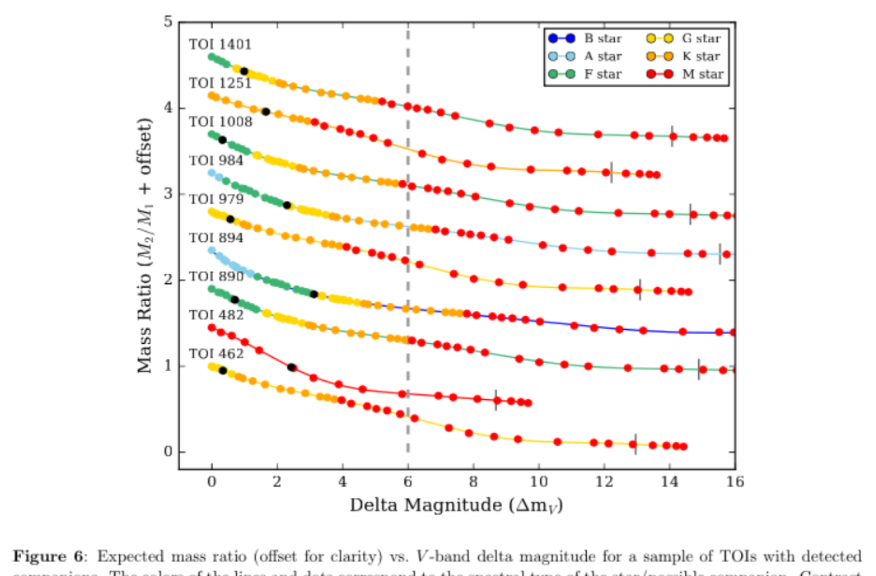


Figure 6: Expected mass ratio (offset for clarity) vs. V-band delta magnitude for a sample of TOIs with detected companions. The colors of the lines and dots correspond to the spectral type of the star/possible companion. Contrast limits for speckle imaging at 562nm with NESSI are shown by the dashed line ($\Delta m \lesssim 6$). The small vertical lines along each line indicate where the mass ratio equals 0.1. The black dots show the measured delta magnitude (562nm, except 832 nm used for TOI 482) for observed companions. See the Appendix for a plot of all detected companions.

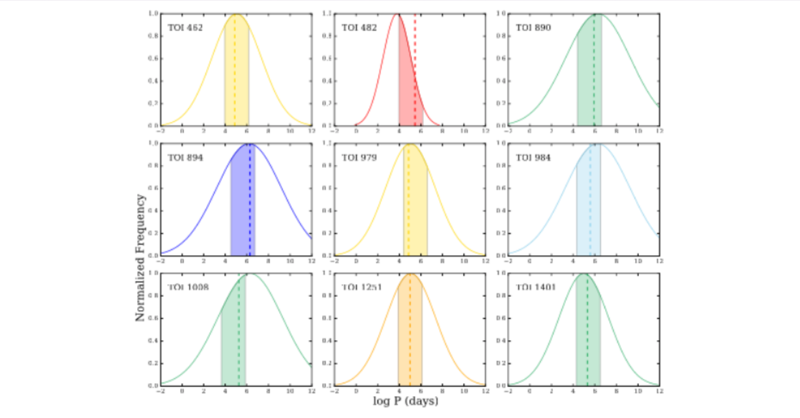


Figure 7: Expected binary period distributions for a selection of TOIs with detected companions based on the distribution presented in Raghavan et al. (2010). The shaded regions (color coded by spectral type of the primary as in Figure 6) show the orbital periods corresponding to projected separations at which speckle imaging at WIYN (562nm) can detect companions. The dashed lines correspond to the separation of observed companions converted to $\log P$ space using the distance and mass of the primary star. See the Appendix for a plot of all binary period distributions.

Using the observed properties of the TESS target star and our detected companion, we can estimate the mass for each star assuming they are physically bound, a very likely situation for companions discovered within 1.2". We show below the estimated mass ratio, revealing a consistent distribution with the standard "Raghavan" distribution. We also show the mass ratio of each binary pair as a function of the approx. orbital separation in au. We note a trend toward lower q values with increasing orbital separation - a curious lack of near-equal masses at wider separations.

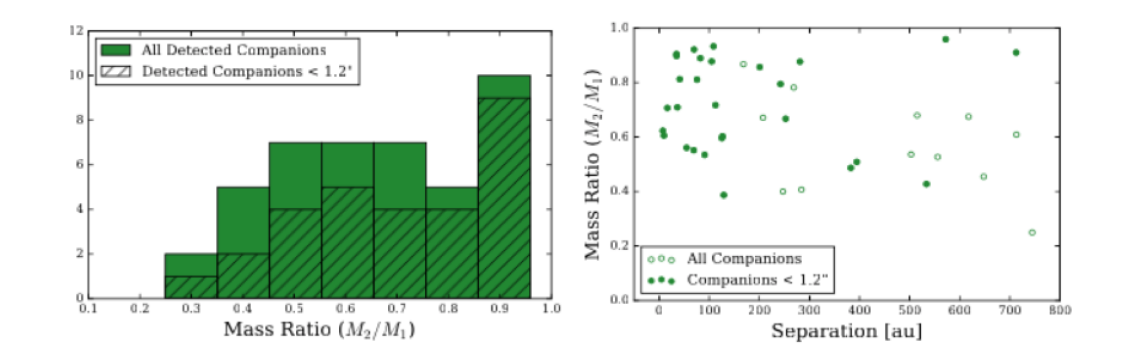


Figure 8: Left: Calculated mass ratios for all companions detected with speckle imaging at WIYN including those detected within 1.2" (hatched bars). The mass ratios were determined using the measured Δmag at 832nm and a polynomial fit to the mass ratio as a function of TESS delta magnitude based on Pecaut & Mamajek (2013). See Figure 6 and the text for more details. Right: Mass ratio as a function of separation in au for all companions (open points) and those detected within 1.2" (solid points).

RESULTS

Taking our projected companion separations, statistically correcting for missing companions and convolving the distribution with our detection contrast curves, we arrive at the result that the mean separation of binary exoplanet host stars is not represented by the standard "Raghavan" distribution, but has a larger mean separation (near 100 au, not 40-50 au) and a narrow width (~0.75 au).

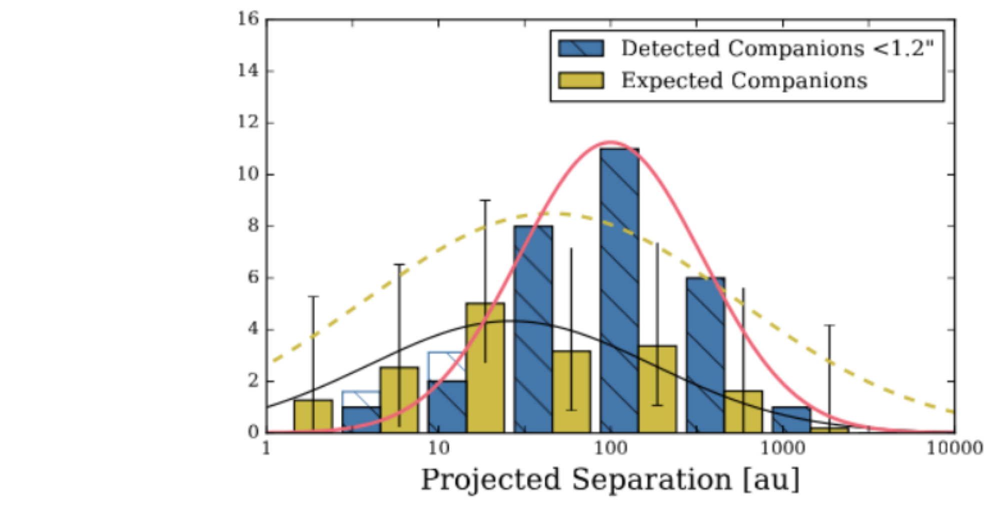


Figure 10: Histogram of projected separation in logarithmic bins of au for companions detected within 1.2" of a TOI at WIYN (solid blue bars). The unfilled hatched bars represent a 'correction' factor based on our mean contrast curve range in delta magnitude over the separation bins in au (see Figure 4 and text for more details). A Gaussian fit to the 'corrected' companion distributions is shown in red, which is narrower and peaks further out than the distribution of Raghavan et al. (2010). Also plotted is the expected number of companions (solid yellow bars) as determined from the "Comp. Frac." and "Distr. Frac" of 46% of the TOIs (see text for details). The Gaussian fit to the expected companion distribution is shown in black, while the Raghavan distribution, scaled to the expected number of companions and bin width, is plotted as a yellow dashed line.